

SOME RESULTS OBTAINED IN STUDYING RIPENING BANANAS WITH THE RESPIRATION CALORIMETER.

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INTRODUCTION.

Various agricultural products that were formerly available to the consumer only in rather limited areas and in quite restricted periods at certain definite seasons, may now be had almost everywhere and at practically all seasons of the year. This is due to modern methods of production and distribution. For many crops the kind of attention paid to details of growing, transportation, and marketing depends largely upon the market for which they are intended. The condition to which fruit, for instance, may be allowed to ripen depends upon the distance to which it is to be transported and the length of time it is to be kept before sale. Some fruit, for example the apple, may be allowed to ripen almost fully on the tree, and if proper attention is paid to handling and storage, may be kept for relatively long periods, and even with improvement of the quality of some varieties. The peach may retain its color and texture and appearance for a considerable time in storage, but its flavor can not be retained. Soft fruits like the strawberry can be kept for only a very short time without deterioration and decay. On the other hand, such fruits as the banana may be picked before the ripening process has begun, transported long distances, and ripened, under favorable conditions, according to the market demand.

PROGRESS OF RIPENING.

The phases of fruit ripening are familiar and easy to follow. Development to full size, the gradual softening of tissue, the change in color (usually from green to red, yellow, purple, or blue), the change in flavor from acid, bitter, or astringent to mild, sweet, or bland, and the development of aroma are the principal steps. When fruit is fully ripened, the processes which have been going on do not cease, but continue with loss of quality. The texture grows too soft,

the flavor becomes flat or unpleasant, the aroma less agreeable, and the color turns frequently to brown or black, and changes occur more rapidly than during earlier stages of ripening. If microorganisms gain access to the fruit, through a broken skin, decay begins. If microorganisms do not gain entrance, the fruit gradually loses its moisture, becomes dry and shrunken, turns dark in color, and generally becomes inedible.

These changes in physical condition or characteristics are indications of the fact that the chemical nature of the fruit has been altered. In the laboratory considerable study has been made of fruit in different stages of ripening to determine what takes place. Some of the changes are quite easy to follow and are fairly well understood. These include the transformation of starch into sugar, the transformation of soluble tannin compounds into insoluble forms, the actual lessening of the quantity of acid, or the masking of the acid flavor by the accumulation of sugar, the softening of woody tissue, and the increase and storage of water (juice). On the other hand, the formation of compounds responsible for special flavor and aroma, such as volatile ethers, organic oils, etc., is not so easy to follow step by step. Yet much is known about the subject and information is accumulating.

Some of the reasons for these changes in the physical and chemical character of fruit were more nearly understood when it was learned that they were brought about by the action of bodies normally present in the fruit tissue, and called enzymes or unorganized ferments, the latter name being due to the fact that the changes which they bring about in the fruit are similar to those which yeast causes in a sugar solution. The action of the enzymes is influenced by physical conditions such as the degree of heat or amount of moisture, the presence or absence of oxygen and other gases, and the presence or absence of light. In some fruits these changes go on apparently about as well after the fruit is gathered as before; at least, the fruit ripened under favorable conditions after it is picked is practically like that ripened on the plant. Such fruit may be picked green and ripened as desired. In other cases the changes which occur in unripe fruits after gathering are not like those of normal ripening and such fruit must be allowed to ripen as completely as possible before picking. In all fruit the action of the vital processes which continue after ripening results ultimately in a loss of quality.

These conditions depend upon the fact that the fruit when taken from the plant, though it can no longer increase its size, still retains its capacity for development, and under favorable circumstances it continues certain of its normal vegetative functions after it is removed from the plant where they had their beginning.

CONTROL OF RIPENING AND ITS COMMERCIAL IMPORTANCE.

In large measure, then, the successful handling of fruit so that its season may be prolonged and its quality maintained necessitates some means of retarding or accelerating ripening at will, in order that the desired quality may be attained at the most favorable time, and of retarding or preventing after-ripening processes which result in deterioration and decay, in order that the season of perfection may be maintained as long as possible. In common practice cold storage, heat insulation, and mechanical refrigeration are employed to retard the ripening of the fruit during shipment, or during the period in which it can be held until needed. Protection from the air, which is usually laden with mold spores and other minute forms of life which cause decay, also plays an important part in storage, since, if these minute forms of life find entrance into the fruit through small breaks in the skin, deterioration and decay will result. On the other hand, use is made of heat, air, and light to accelerate ripening. Sometimes bringing the fruit from the cold-storage warehouse into a room of ordinary temperature is sufficient; sometimes, as in the case of the banana, warmer temperatures are needed. In the application of these facts have grown up the great industries of fruit transportation, storage warehouse business, and other developments of the modern fruit trade. The methods employed, though on a very different scale, are largely those of the housekeeper who holds back the ripening of fruit by keeping it in a cool cellar, ice chest, or refrigerator, and hastens the ripening, for instance, when she puts an underripe melon in the sun, or puts her tomatoes in the kitchen window, or her hard apples and winter pears in a room of moderate temperature.

LABORATORY STUDIES OF RIPENING BANANAS.

Numerous investigators have studied problems concerned with the ripening of fruits under different conditions. It is not the purpose in the present article to bring together the results of their efforts, but rather to cite a few of them for the purpose of showing the kind of work that has been and is being done with bananas to obtain knowledge of the principles on which may be based sound and satisfactory practice. For instance, the Jamaica department of agriculture¹ made studies of the gases given off by oranges and bananas, with particular reference to the possibilities of shipment. The carbon dioxid liberated by the ripening oranges was thought to be a preservative of bananas, though, on the other hand, gases or emanations given off by the oranges were thought to induce premature ripening. The practical deduction was drawn that separate storage was desirable for the two sorts of fruit during sea transportation.

¹Ann. Rpt. Dept. Agr. [Jamaica], 1910, p. 6.

The chemical changes occurring in the ripening banana have been studied by a number of investigators, including Tallarico,¹ Yoshimura,² Reich,³ and Bailey.⁴ The results of such work as theirs have shown that during the ripening of the fruit the starch is transformed into saccharose (cane sugar), which gradually increases in amount and is, in turn, converted partly or wholly into a mixture of dextrose and levulose, "invert sugar," the proportion varying according to circumstances. The presence of other kinds of sugar has not been demonstrated.

Chemical analyses showed the green fruit to contain on an average about 1 per cent of reducing sugar, the amount increasing until the fruit when ripened to the yellow stage contained about 6 per cent and the brown (very ripe) fruit about 11 per cent. The amount of cane sugar increased from about 6 per cent in the green to a maximum of about 11 per cent in the yellow fruit and then diminished to about 6 per cent in the brown (very ripe) bananas. The total carbohydrates (starch, sugar, etc.), which made up about 21 per cent of the green fruit, reached a maximum of about 22 per cent in the yellow banana, and diminished to about 17 per cent in the brown (very ripe) fruit. Water and tannin substances remained fairly constant throughout the ripening. The changes in acids, in proteins, and in fats were also investigated, but no general deduction seems warranted.

Studies of the agencies which cause banana ripening have shown that various enzymes or "unorganized ferments," which are present normally in the banana, take part in the process. The presence of a number of these ferments has been demonstrated by various chemists. The action of catalase, an enzyme which accelerates oxidation processes, is intense during the ripening, but gradually disappears in the fully ripe and blackened fruit. Amylase, the enzyme transforming starch into sugar (maltose), is active during the early stages of ripening, and its presence has been found even in the ripened fruit. The presence of invertase (sucrase), which brings about the inversion of cane sugar to dextrose and levulose, has been shown in the unripe fruit, but its action is much more intense in the ripened fruit and gradually disappears as the ripening process ends. Alkalinity retards or inhibits its action. Protease, a protein-splitting ferment, has been found and is active during the ripening period, but its action probably diminishes and disappears afterwards. The action of the lipases, as fat-splitting enzymes are called, has been demonstrated in both the unripe and ripe fruit. The hydrolysis of raffinose by banana tissue was shown, but the specificity of the enzyme effecting this hydrolysis was not established.

¹ Arch. Farmacol. Sper. e Sci. Aff., 7 (1908), p. 27.

² Ztschr. Untersuch. Nahr. u. Genussmtl., 21 (1911), p. 406.

³ Ztschr. Untersuch. Nahr. u. Genussmtl., 22 (1911), p. 208.

⁴ Jour. Amer. Chem. Soc., 34 (1912), p. 1706.

In reporting the results of chemical studies which give data regarding the mineral matter as well as other constituents of unripe and ripe bananas, one investigator concluded that during the ripening of a bunch of bananas under commercial conditions the change of starch into sugar is normal, but that the inversion of cane sugar is slower than it is when the fruit ripens on the plant and that it progresses less favorably. Whenever the cane sugar content of the bananas was much higher than the invert sugar the fruit seemed unripe and lacking in aroma.

Studies of bananas during the ripening period, which have been made by the Bureau of Chemistry of this department, and which still await publication, deal with the changes which take place in the carbohydrates and other constituents and their causes. The respiration calorimeter experiments of the Office of Experiment Stations, such as are reported in this article, furnish information particularly regarding the respiration of the banana and the energy transformations involved, as measured by the gaseous exchange and heat output. The results correlate and supplement those obtained by chemical methods.

It has been suggested that the heat liberated by bananas during the active ripening period is due to bacterial activity rather than to enzymic changes, but results of bacteriological studies reported by E. M. Bailey¹ indicate that this is not the case.

From his studies he concludes that—

the inner portions of the pulp of sound bananas are practically sterile, but that the regions of the inner coats of the peel may be sparsely inhabited by bacteria, which, during normal ripening processes, are held in check, but subsequently find conditions favorable to growth. The resistance of the protective covering of the fruit to invasion by bacteria points to the circulation of the plant juice as a more probable channel of infection, and suggests that infection occurs while the fruit is still on the tree.

The laboratory work which has been done up to the present is not very large in amount, yet it has proved very useful. Out of the knowledge thus gained with bananas and other fruits and the larger volume of knowledge gained by experience the present elaborate system of shipping and storing bananas has developed and become an industry of great proportions and representing an enormous investment. The numerous losses and the uncertainty of results show that perfection in methods has not yet been attained.

Bananas are usually shipped by water from the tropical regions where they are grown to the distributing centers. Ships especially equipped for the purpose are used. The rapid growth of the industry may be seen when it is recalled that 30 or 40 years ago bananas were a great rarity in the United States, except in a few seaboard towns, while now they are common in every region. In Great

¹ Jour. Amer. Chem. Soc., 34 (1912), p. 1706.

Britain the condition is even more striking, for the banana, little known 15 years ago, is now the "poor man's fruit." The banana steamers, particularly those designed for long trips, are equipped with specially constructed chambers for holding the fruit so that bruising will be reduced to a minimum, and with special devices for forcing cooled, chilled, and dried air through the chambers so that the banana may remain green until it reaches its destination.

Although so much has been accomplished as a result of study and experience, other problems must be solved if losses are to be reduced to a minimum and quality insured. For this reason the study of banana-ripening problems was undertaken by the United States Department of Agriculture.

THE RESPIRATION CALORIMETER AS AN AID TO THE STUDY OF FRUIT RIPENING.

To assist in satisfying the demand for such information the department has given considerable attention to the study of the problems of fruit ripening. The changes of physical and chemical nature which occur in fruit ripening under various conditions have been followed. It has been found that these changes are accomplished by the taking of oxygen from the atmosphere and the liberation of carbon dioxid, and that, as in the case of most chemical changes of this character, there is a corresponding liberation of heat. In other words, the ripening fruit resembles an animal in that it breathes in oxygen and gives off carbon dioxid, and in the performance of its vital processes liberates heat. For comprehensive knowledge regarding the changes taking place in the ripening fruit, some method of studying simultaneously the gaseous exchange and the energy transformation occurring during the process was essential. The results obtained with the respiration calorimeter employed in the study of such factors in investigations in human physiology indicated that such an apparatus that could be employed likewise in similar investigations in plant physiology would be advantageous, and some tests with fruit in the chamber of the large calorimeter showed that such a device could be readily adapted for such work. Accordingly, as pointed out in an earlier volume¹ of this series, cooperative experiments were undertaken by the Bureau of Chemistry and the Office of Experiment Stations. To facilitate the work a special respiration calorimeter of suitable size was constructed for the purpose. The special problem selected was the study of bananas during the period which corresponds to commercial ripening in banana cellars or warehouses; that is, the period during which the green banana as received from the shipper is held in the warm, moist conditions, until it ripens, turns yellow, and is ready for the retailer, which requires approximately one week. The results of a typical

¹ U. S. Dept. Agr. Yearbook 1910, p. 307.

experiment on the ripening of bananas in this apparatus are discussed in the pages beyond. In general, it may be said that the phenomena observed and studied quantitatively in these respiration-calorimeter experiments with bananas yield new data for judging of the character and extent of the changes involved in ripening. It is believed that the results of such studies, taken together with those obtained by other methods, when interpreted, will be of value to the producer, shipper, and dealer by enabling them to improve their methods, lessen losses, and improve quality.

The respiration calorimeter with which the experiment was made was designed especially for investigations of this character, and has been described in considerable detail in former publications of the department.¹ In brief, it may be explained that the significant feature of the apparatus consists of a respiration chamber that is both air tight and heat proof, which affords an opportunity to measure the gaseous exchange and energy transformation that take place within it.

To measure the gaseous exchange, the air of the chamber is kept in constant circulation, being withdrawn by a rotary air pump through a pipe in one wall, passed through purifying devices and returned to the chamber through another pipe, at a rate of circulation of about 10 liters per minute.

In the train of purifying devices the air is passed first through sulphuric acid, which removes all the water vapor from it, and next through soda lime, which removes all the carbon dioxid. The sulphuric acid and soda lime bottles are weighed at stated intervals, the increase in weight showing how much water and carbon dioxid were absorbed during the intervening period.

At the beginning and end of each period analyses of the air remaining in the chamber are made, which show what changes have taken place in the moisture and carbon-dioxid content of the air during the period. These data are taken into account with those for the quantities absorbed from the circulating air to determine the amounts produced during the period. Changes in volume of the air of the chamber due to differences of temperature and of barometric pressure at the beginning and end of the period are also considered.

Oxygen to replace that used by the bananas is admitted to the chamber from a cylinder which is weighed at the beginning and end of the period. The loss in weight of the cylinder, the gain or loss in the percentage of oxygen in the residual air, as determined by analysis, and the difference in volume due to changes in temperature and barometric pressure are data from which the amounts of oxygen consumed by the fruit are determined.

In order that the energy transformations occurring within the chamber may be measured, the gain or loss of heat through the walls

¹ U. S. Dept. Agr. Yearbooks 1910, p. 307; 1911, p. 491.

is prevented. To this end the chamber has double parallel walls of sheet copper separated by a small air space. Provision is made for keeping the temperature of the outer wall exactly the same as that of the inner wall, in which case heat will not pass from one to the other in either direction.

Part of the heat generated by the bananas is carried out as latent heat of water vapor in the ventilating air current. This is determined by multiplying the weight of water vapor removed from the air by the factor 0.586, which represents the amount of heat required to vaporize one gram of water at 20° C. The remainder of the heat liberated in the chamber is taken up by a current of cold water flowing in a coil of copper pipe, called the "heat absorber," hanging in the air of the chamber surrounding the bananas. The quantity of water flowing in a given period through the heat absorber is weighed. The difference between the temperature of the water just as it enters and that just as it leaves the calorimeter chamber is continuously recorded automatically. The product of the weight of water for a given period and its average temperature difference is the amount of heat carried out during the period. The sum of these two quantities is practically the amount of heat produced by the bananas, though changes in temperature of the walls of the calorimeter and in the bananas themselves are also taken into consideration.

The temperature of the water entering the heat absorber is automatically maintained constant at any point desired within 0.05°. This temperature and the rate of flow of water are regulated so that the absorption of heat in the chamber will follow its generation in such manner that the temperature of the air in the chamber will remain practically constant at any given point.

Once an experiment has begun, the apparatus, as a calorimeter, because of improvements in it and in methods, is practically self-operating, yet very accurate. The instrument as a respiration apparatus has been improved also until the work of operating it has been greatly reduced. The purifying devices require attention only at the ends of the periods, when change is made from one train to the other. The train that has been in use is then weighed, replenished, and again connected and tested, in readiness for the change at the end of the new period.

The details of an experiment with a bunch of bananas in this respiration calorimeter are given in the following pages.

AN EXPERIMENT WITH BANANAS RIPENED IN THE RESPIRATION CALORIMETER.

Bananas usually come to the Washington market in the early part of the week, and the best ones are commonly disposed of quickly. For these experiments bananas are generally obtained shortly after they are unloaded from the freight car, so as to have them as green

as possible, and care is taken to make selection from those that show no indication that ripening has begun. This affords opportunity to follow the changes occurring during the whole of the commercial ripening period. It is a part of the plan followed to study bananas of different grades. The bunch used in the present experiment, however, was somewhat more mature than those usually obtained. As a whole the shipment from which this bunch was selected was not particularly fine, and the bunch chosen was not first grade, being rather what would be known commercially as "seconds," and not a particularly fine quality of that grade. It was a rather small-sized bunch, weighing only 12.29 kilograms when put into the respiration chamber, and the bananas on it were also only medium or small in size. The stock from which the bananas were selected was not as green as the average shipment, but one of the greenest bunches was taken. When the fruit reached the laboratory, toward the middle of the afternoon on January 2, its temperature was considerably below 20° C., which was that at which it was intended to keep the bananas during the ripening period. The bunch was therefore allowed to hang in the laboratory until about 10 o'clock on the following morning, at which time it had become sufficiently warm to be put into the calorimeter chamber. By this time there were faint suggestions of changes of color of the skin of the banana from green to yellow. The bunch was then weighed and put directly into the respiration chamber and the cover of the latter sealed on. The usual analysis of the air residual in the chamber at the time of sealing in the bananas was not made, but all the carbon dioxid or water vapor generated in it was retained there. The purifying system was made tight and the air circulation started by 2 p. m., January 3, but the recording of experimental data did not begin until a little later, the intervening time being employed as usual in bringing the calorimeter into a condition of thermal equilibrium between the inside and outside metal walls of the chamber. At 5.45 p. m., everything being in readiness for the experiment, an analysis was made of the residual air in the chamber, the circulating air was shunted from one purifying system to the other, and the first regular period of the experiment began.

The experiment as a whole continued almost five days, and was divided into five periods each of practically a day's duration. The ripening of the fruit continued regularly, and each day the change in color from green to yellow, as seen through the window of the respiration calorimeter, became more noticeable. On the morning of January 6, though a bit of green color still persisted at the extreme tip, the bananas appeared to be fully as ripe as they would be found under ordinary commercial conditions, if not indeed a little beyond that stage. Dark patches on the skin were quite distinct, and

some dark lines appeared along the ridges on the fruit. Some of the individual bananas seemed to be a little shrunk. However, in order that there might be no doubt as to the full ripeness of the bananas when taken from the respiration chamber, the experiment was continued until the close of the following day, January 7.

At the end of the experimental period the cover of the respiration chamber was unsealed, and the fruit was removed and weighed immediately, the weight of the bunch being 11.59 kilos. The fruit was then examined as to its commercial quality. The skin of the bananas felt somewhat dry and appeared to be very slightly wilted, with dark lines and patches which were quite pronounced. The pulp was somewhat dry and mealy, just tending toward too great softness, though it was not sour or overripe; in fact, it was more nearly in the best condition for eating than bananas commonly sold in the market, since under commercial conditions fruit that has reached that stage of ripeness begins so soon to pass to overripeness and to decay that it can no longer be sold for good prices. The flavor of the fruit was delicious, and its aroma, which was noticed especially on opening the respiration chamber, was very pleasing.

In brief, bananas in the condition of these at the close of the experiment would be much more satisfactory to the consumer than the underripe fruits so commonly sold. To the dealer, on the other hand, they would not be so satisfactory unless they could be sold quickly, because if they had to be kept any length of time they would become overripe and would not bring good prices. The data obtained in the experiment are summarized in the following table:

Summary of data obtained in respiration calorimeter experiments with ripening bananas.

Date.	Dura- tion of period.	Tem- pera- ture of air in cham- ber.	Tem- pera- ture of bana- nas.	Per cent of oxygen in air.	Water pro- duced.	Carbon dioxid pro- duced.	Oxygen con- sumed.	Heat pro- duced.	Res- pira- tory quo- tient.	Ther- mal quo- tient.
	<i>Hrs. min.</i>	<i>° C.</i>	<i>° C.</i>		<i>Gm.</i>	<i>Gm.</i>	<i>Liters.</i>	<i>Calo- ries.</i>		
Jan. 2.....	7 45	20.6	21.4	18.00	122.7	10.9	16.0	13.3	0.92	.....
Jan. 3.....	23 15	20.9	22.4	17.69	124.2	43.6	21.6	131.0	1.03	3.00
Jan. 4.....	23 ..	20.6	21.6	20.41	122.4	43.8	22.2	113.0	1.00	2.58
Jan. 5.....	24 ..	20.5	21.3	19.43	116.9	38.7	18.4	100.1	1.07	2.50
Jan. 6.....	24 ..	20.5	20.7	20.01	112.3	33.8	16.6	87.0	1.04	2.57
Jan. 7.....	23 40	20.5	21.1	24.23	106.2	31.3	13.7	87.0	1.16	2.78
Totals and averages...	125 40	.....	.....	.....	604.7	202.1	98.5	531.4	1.04	2.68

¹ These figures do not include corrections for the amounts present in the residual air of the chamber at the beginning of the preliminary period, since no analysis of the air was made at that time.

² This figure for Jan. 2 represents only the heat due to the vaporization of the water in the outgoing air.

³ This figure for heat measured during this period is somewhat larger than that actually produced by the bananas.

The first two columns in the table on page 302 show the date and the length of the several periods into which the experiment was divided. The preliminary period, as already explained, continued from the time when the bananas were sealed in the respiration chamber until the circulating-air system was changed from one set of purifying devices to the other. For convenience the first and second day periods were made a little less than 24 hours each, while the last period ended 20 minutes before the completion of the full day.

The second column shows the temperature of the air in the chamber at the end of each of the several experimental periods. The third column shows the temperature of the bananas themselves, as indicated by a special electrical resistance thermometer, long and slender in form, which was pushed between the bananas deep into the bunch, but which did not actually penetrate the fruit. The temperatures of both the air and the bananas were read at frequent intervals during each day, so that any fluctuations could be readily detected. In the case of the air surrounding the bananas, care was taken to prevent any very wide fluctuation in temperature. The temperature of the air in the chamber is regulated by controlling either the rate of flow or the temperature of the water circulating in the heat absorber adjacent to the bunch of bananas in the respiration chamber. The temperature of the bananas themselves, of course, varied with the activity of the ripening processes. It is essential to know the change in the temperature of the fruit in order to make correction for the amount of heat involved in such change in determining the total quantity of heat produced by the bananas. It will be observed that the temperature was highest during the first regular period, January 3, and that from this day it fell off gradually until the last day, January 7, at which time it was for some reason apparently slightly higher than on the day just preceding.

The fourth column shows the percentage of oxygen in the air of the respiration chamber at the end of each period, as determined by analysis of a sample of air drawn from the chamber at that time. It is essential to know what change has taken place in the oxygen content of the air at the end of a given period in order to determine how much oxygen has been used during the period. The data are given here simply to show the limits of variation that were found. They give no indication, however, of the proportion of oxygen present in the air during the whole of the period, as this would vary with changes in the temperature or the barometric pressure of the air, or with the care taken to fill the air tension equalizer always to the same point and at regular intervals. Most of the time oxygen was introduced into the chamber in such quantities as would keep the proportion of oxygen in the air not far from 20 per cent. During the second

experimental period, when the activity of the banana was greatest, the temperature and barometric pressure conditions were such that the proportion of oxygen in the air diminished somewhat, but it was increased to normal again during the succeeding period and was maintained at normal during the rest of the experiment. The high percentage shown in the table at the end of the last period was due to the fact that an excess of oxygen was accidentally admitted just before the last period was terminated.

The fifth column shows the amount of water produced by the bananas during each period. This is ascertained from a gain in weight of the first water absorber (a bottle containing concentrated sulphuric acid) in the air-purifying system, and from the increase or decrease in the quantity of moisture present in the air residual in the chamber at the beginning and end of the period. At the end of the preliminary period, January 2, the water absorber had gained 22.7 grams, owing to moisture removed from the circulating air. It can not be stated how closely this represents the total quantity of moisture produced during this period, because the air was not analyzed at the beginning of the period, hence the increase in the quantity of moisture residual in the air of the chamber could not be determined. The quantity of moisture given off by the ripening bananas in the first regular period would appear, from the table, to be slightly larger than that of any of the others, but that in the second period was practically identical with it when the small difference in the length of the periods is taken into account. There was a small but continuous decrease in quantity of moisture eliminated by the bananas in each successive period, in conformity with the decrease in the intensity of the ripening processes.

The moisture content of the air surrounding the bananas in the chamber depends entirely on the elimination of moisture by the bananas themselves, because the circulating air returning to the chamber is absolutely dry after having passed through the purifying system. During the whole of the experiment the relative humidity of the air was somewhat below the point of saturation for the temperature of the air. It was greatest during the first two periods, and decreased gradually as the activity of the bananas diminished.

The total quantity of water eliminated by the bananas during the whole of the experiment was 604.7 grams, which was almost one-twentieth, or 4.9 per cent, of the total weight of the bananas put into the chamber.

The quantities of carbon dioxid eliminated by the bananas during the several periods are shown in the sixth column. These are determined from the increase in the weights of the carbon dioxid absorber (a bottle of soda lime followed by a bottle of sulphuric acid) of the

air-purifying system, together with the changes in the quantities of carbon dioxid in the air of the chamber at the end of each period. The quantity given for the preliminary period, January 2, is only approximate, because no correction was made for the amount present in the air of the chamber at the beginning of this period. As in the case of the water, the largest amounts of carbon dioxid were eliminated the first two experimental days, being almost the same for both. The quantities for the succeeding days showed a gradual decrease.

The quantities of oxygen utilized by the bananas for the ripening processes are indicated in the seventh column. At least, these represent the quantities taken by the fruit from the circulating air, as shown by the loss in the weight of the cylinder from which the oxygen was supplied to the chamber, and the change in the oxygen content of the air of the chamber at the end of each period. It is possible, of course, that oxygen may have been available to the fruit from some other source also. It is conceivable, for instance, that there may have been a supply of oxygen in the tissues of the plant, or oxygen may have been derived from the transformation of some of the compounds of the fruit. However, it is noteworthy in this connection that utilization of oxygen from the air kept pace very evenly with the elimination of carbon dioxid. This is shown quite clearly by the figures in the ninth column, designated as "respiratory quotients."

The respiratory quotient represents the ratio of the volume of oxygen consumed to that of the carbon dioxid produced; that is, it is the quotient found by dividing the latter by the former. In the combustion of carbohydrate material, the volume of carbon dioxid produced is exactly the same as that of oxygen consumed; that is, the respiratory quotient is 1.00. It is noticeable that for each of the regular periods of this experiment the respiratory quotient is not far from unity, the most noticeable deviation being on the last experimental day, January 7. Considering the experiment as a whole, the ratio between the carbon dioxid production and oxygen consumption is 1.04. This appears to be at least a fair indication that the metabolic processes representing the ripening of the bananas were essentially equivalent to an oxidation of carbohydrate.

The quantity of heat produced by the bananas, as a result of the transformations mentioned above, is indicated in the eighth column. For the preliminary period, January 2, the quantity given represents only the heat due to the vaporization of the water absorbed from the air leaving the respiration chamber, because part of the time represented by this period was utilized to bring the internal and external metal walls of the chamber into thermal equilibrium, in which process heat may be gained or lost by the chamber through

the walls, and this would affect the quantity of heat measured by the calorimeter, and supposed to be given off by the bananas.

As a matter of fact, such an error actually occurred in the measurements of heat during the first regular period of the experiment, January 3. The quantity indicated by the table as having been eliminated by the bananas is 131 calories. This value, however, is somewhat too large, because during the early part of this period there was not thermal equilibrium between the inner and outer metal walls at the bottom of the chamber, nor between the ingoing and outgoing air. Heat was being introduced at both places, so that it is certain that the amount of heat measured by the calorimeter in this period is larger than that produced by the bananas, though just how much larger can not be exactly stated.

In the succeeding experimental period, January 4, which was only 15 minutes shorter than the one before it, the amounts of water (122.4 grams) and of carbon dioxid (43.8 grams) given off and of oxygen (22.2 grams) absorbed by the bananas were almost identical with the corresponding quantities of the previous period, but the amount of heat measured in the second period was only 113 calories. It is very probable that this more nearly represents the amount of heat generated in the first period also than the value recorded in the table.

There was a gradual diminution in the quantity of heat produced in the succeeding periods, although in the last period, January 7, the quantity shown in the table is exactly the same as that for the next to the last period. This appears to have been due to the fact that the temperature of the bananas seems for some reason to have increased somewhat toward the close of the final period, and the amount of heat involved in such a temperature increase is, of course, included, together with that measured in other ways, in calculating the total amount of heat produced by the bananas during the time covered.

The figures in the last column of the table are designated as "thermal quotients." The figure for each period simply represents the numerical ratio between the grams of carbon dioxid produced and the calories of heat produced during the period. In the combustion of carbohydrate (starch), for each gram of carbon dioxid produced 2.58 calories of heat is produced. It is noteworthy that this figure is almost identical with that for three of the periods in this experiment. The thermal quotient for the first period is given as 3.00, but this is too large, because of the fact explained above, that the heat production during this period is known to be too large. If the heat production given in the table for the second period were taken to represent that for the first period also, which is undoubt-

edly more nearly correct than the figure actually given for this period, the thermal quotient for that period would be 2.6. The increase in the heat production for the last period referred to above results also in a thermal quotient slightly larger than that for the remaining periods. The quotient for the experiment as a whole is 2.63. This value, like the respiratory quotient, may also be considered a fair indication that the metabolic activity in the banana during this experiment was equivalent to those involved in the combustion of carbohydrate.

The data obtained in this experiment do not show with certainty the particular carbohydrate which was oxidized. It may have been any one or some of all of the carbohydrates present in the fruit, namely, starch, cane sugar, or invert sugar. This is apparent when it is recalled that approximately 125 grams of starch, or 130 grams of cane sugar, or 140 grams of invert sugar would yield on combustion the quantities of carbon dioxid and energy produced by this bunch of bananas. The fact that the value found agrees so nearly with the theoretical value for any one of these carbohydrates indicates that other constituents of the banana, as tannin compounds, aromatic and flavoring bodies, and proteids were not concerned in the energy transformations to any extent, or, if they were, that the amount of heat they utilized exactly balanced the amount they produced.

GENERAL CONCLUSIONS.

A consideration of available experimental and other data shows that the successful handling of fruit during transportation, in the cold-storage warehouse, and in the home depends upon a knowledge of the changes which take place in ripening, after ripening, and decay, and the causes of these changes and ways in which they may be controlled. Present practice is based on knowledge gained by experience, supplemented by work carried on in the laboratory.

The respiration calorimeter offers a new means for studying fruit-ripening problems, and the results are briefly presented of a study made with bananas during the active ripening period. The results show that the ripening changes progress regularly to a maximum and then decline; that at its greatest intensity the heat produced is equivalent to approximately one calorie per hour per kilogram of bananas. The heat liberated is a measure of the activity of one or more of the ripening processes. Analysis has shown that during ripening the banana starch is transformed into cane sugar and the cane sugar into invert sugar, and that there are important changes in the character of the tannin compounds, and that other changes occur, brought about by the production of aroma and flavor bodies, and perhaps in other ways. It has also been found that in addition to the trans-

formation of carbohydrates there is an actual loss of this food constituent during ripening. From the data for oxygen consumption, carbon dioxid, and heat output it appears that the heat liberated by the ripening bananas is largely due to the destruction of carbohydrate. The results here recorded and discussed represent only a part of the material which is being accumulated. No attempt is made at this time to draw deductions regarding the practical applications which can be made, as this may be done more properly when experiments now under way are completed.